BNL-211216-2019-TECH

NSLSII-ASD-TN-284

RCDS online optimization the NSLS-II dynamic aperture and injection transient

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September 2018

Photon Sciences

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC), Basic Energy Sciences (BES) (SC-22)

DISCLAIMER

NSLS II TECHNICAL NOTE BROOKHAVEN NATIONAL LABORATORY	NUMBER **NSLSII-ASD-TN-284**
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September 24, 2018

Abstract

Previous beam-based nonlinear dynamics optimization study at NSLS-II includes measurement and correction of certain nonlinear characteristics, such as amplitude-dependent detuning and the resonance driving terms. However, these efforts have not yielded definitive evidence that indicates a clear improvement of the dynamic and momentum apertures. We use beam-based measurements to directly optimize the nonlinear beam dynamics with online algorithms, such as RCDS [1]. The optimization objective is injection efficiency and the optimization variables are the strengths of sextupole magnets. We have achieved ~20% increase in the horizontal dynamic aperture (DA) and more than a factor of two reduction of the horizontal tune shift with amplitude. Besides, the preliminary test of minimizing the injection transient via RCDS online optimization of the injection kicker bump matching yields a factor of 5 reduction in the injection beam oscillation.

Introduction

This Facility Improvement Project “Methods of online optimization of NSLS-II storage ring concurrent with user operations” is dedicated to develop a complete set of software tools for online optimization of linear optics, nonlinear beam dynamics, and orbit stability, and online minimization of the injection transients. The online optimization approach is based on use of the measured machine and beam parameters to evaluate the performance functions, which can be optimized using advanced algorithms designed to work reliably in noisy environments. In the project, we will explore performances and limitations of existing optimization algorithms and also develop new algorithms and diagnostics.

The cutting-edge square matrix method recently developed at NSLS-II [1] will be further advanced by combing the linear and nonlinear lattice optimizations together therefore guaranteeing a true global optimal solution. We will use it to optimize the NSLS-II lattice model and to apply the optimal solution to the storage ring. To improve the lifetime and injection efficiency, direct optimization of sextupoles by beam-based model-independent online methods will be used. The injection transient will be also minimized by online optimization of the injection kicker bump matching.

The NSLS-II user community will benefit from reduced top-off injection frequency, improved beam stability, and transparent injection, which could provide uninterrupted data acquisition for the beamline experiments. Since non-linear beam dynamics is a subject of high scientific interest, the results of this project will be beneficial not only for NSLS-II but also for other facilities in operations and for future light source projects.

Study Results

RCDS online optimization DA and Tune Shift with Amplitude via storage ring sextupole tuning

We reduce the SR injection kicker voltage to 58% of the nominal values, the injection efficiency becomes less than 10%. RCDS online optimization of sextupole settings recovers the injection efficiency to greater than 50%. We find in the experiment that two to three iterations are needed to make the solution more robust. Afterwards, more iterations are not so effective, the injection efficiency goes from mild improvement to no improvement at all, as show in Fig. 1 (left). The change of sextupole power supply current by family is shown in the right plot.

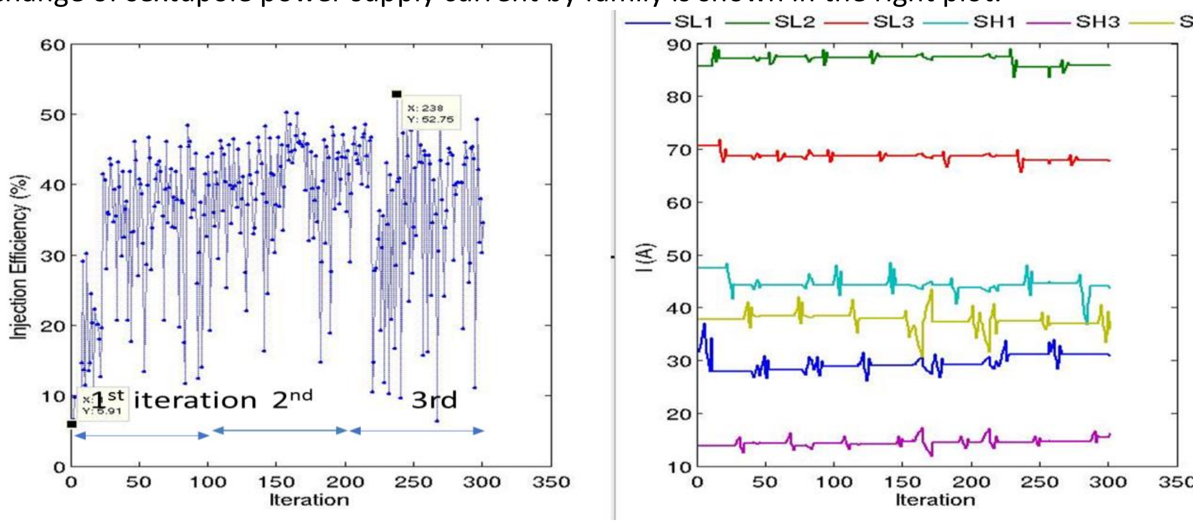

Fig. 1 Injection efficiency during the 3 iterations of the RCDS online optimization of sextupole settings (left). The change of sextupole power supply current by family (right),

We characterize DA by injecting 2mA beam current to 50 buckets which are well aligned on the flat top of the pinger waveform. Afterwards, we gradually increase the pinger voltage. At each step, we record the beam current via the DCCT monitor. Horizontal (left) and vertical (right) DAs before (red) and after (blue) RCDS online optimization in the 3DW operational lattice condition are shown as Fig. 2. We have achieved >20% increase in the horizontal DA with essentially no change in the vertical DA. We also analyze the data for the tune shift with amplitude, before (right) and after (left) optimization are shown in Fig. 3. There is a more than a factor of two reduction in the horizontal tune shift with amplitude.

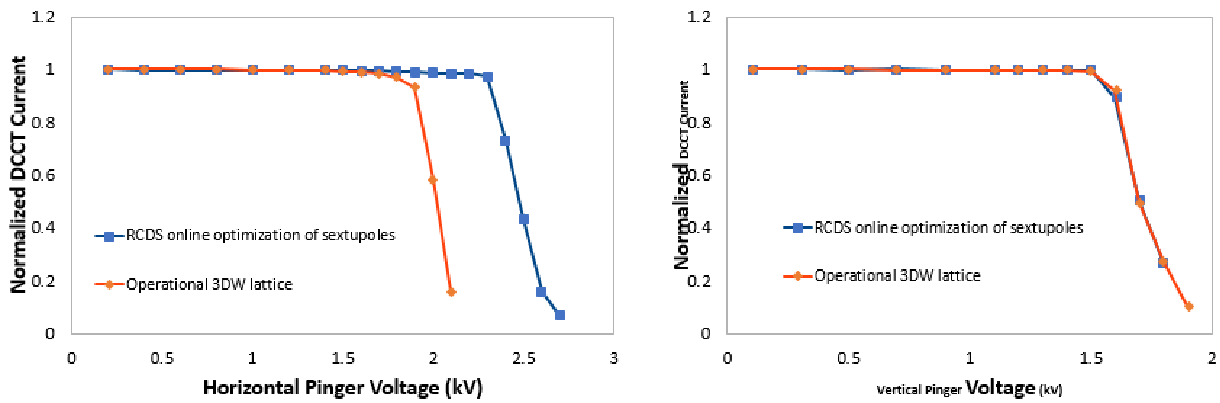

Fig. 2 Horizontal (left) and vertical (right) DAs before (red) and after (blue) RCDS online optimization in the 3DW operational lattice condition.

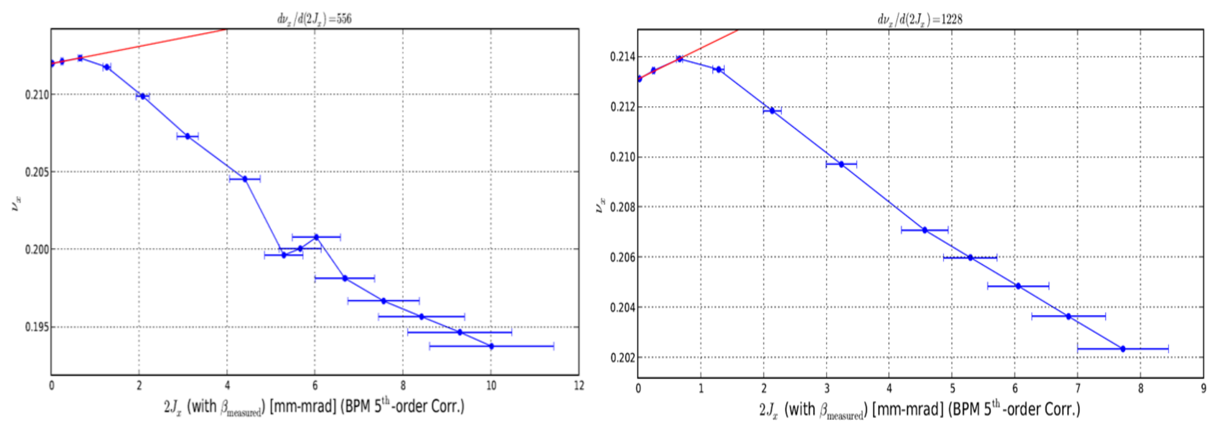

Fig. 3 Horizontal tune shift with amplitude before (right) and after (left) RCDS online optimization.

Minimize injection transient During beam study, we used the Matlab environment [2]. The goal is to minimize beam residual oscillation during top off injection with one long bunch train, 80% bucket fill and small bunch to bunch charge variation. The parameters to be adjusted are the amplitude and timing delay for kicker 1, 2 and 3 while the kicker 4 parameters are fixed. So, there are a total of 6 variable knobs. The residual oscillation amplitude is measured with 180 BPMs turn by turn position in x plane. The objective function is the RMS value of betatron oscillation from a few turns' data after kick excitation.

During the study, the initial kickers' setting is in operation value, with the same kicker amplitude. We did the optimization in three steps with different knobs combination. First, we varied 3 kickers' amplitude only and monitored the residual betatron oscillation from one fixed bucket excitation. This step showed very fast converges, within one hour, and minimized the injection transition from mm close to noise level, ~0.1 mm peak to peak, which is dominated by kickers' shot to shot variation. With the optimized kicker amplitude set, we varied 3 kickers' timing delay further and repeated the same optimization process. As predicted, the above two steps worked very well to minimize the injection transition in a fixed injection bucket, but other buckets still have large transition. In the last step, we varied both amplitude and timing with all the buckets excitation, from bucket 0, 100, to 1000, similar to top off injection and the objective function is the average value RMS value in each bucket. This step benefits from the first two steps' optimization by setting the knobs close to optimal value, but still took longer, about four hours to reach minimum, as shown in Figure 4, the BPM TBT residual oscillation along SR in many turns. The peak to peak oscillation improves obviously, from 1 mm with original set (top) to 0.1 mm after optimization (bottom) for a fixed bucket injection. Since the residual oscillation is injection bucket dependence, Figure 5 compares oscillation RMS value at different injection bucket with different kicker optimization result.

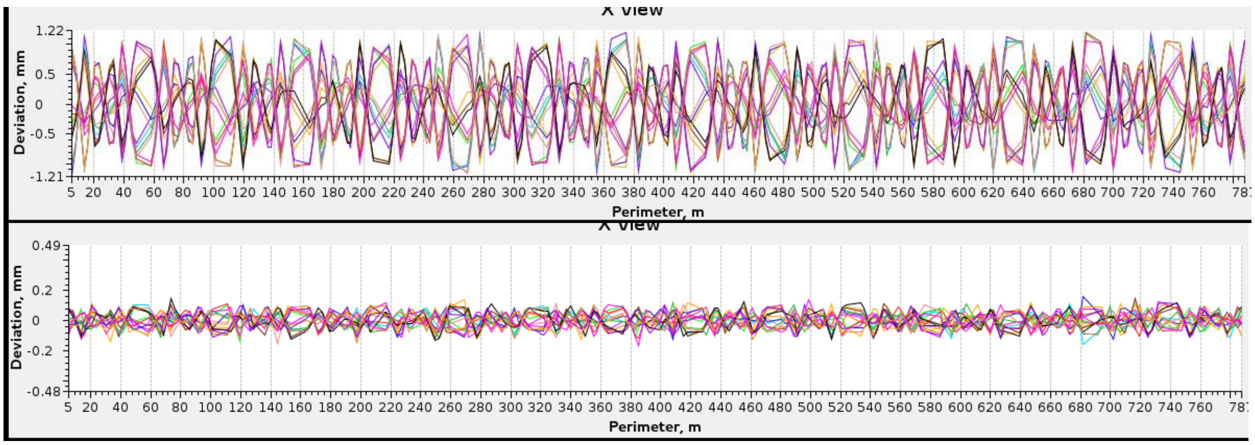

Fig. 4 Top off injection transition from BPM TBT data before (top) and after (bottom) kicker optimization.

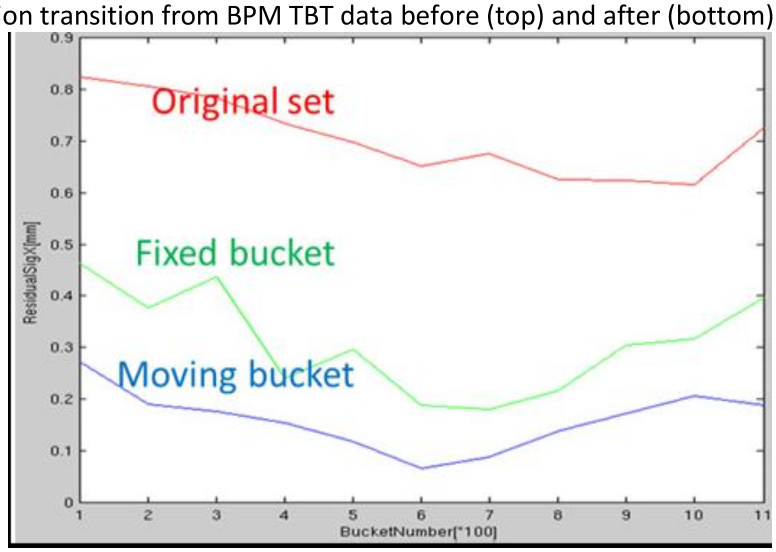

Fig. 5 BPM TBT data RMS value dependence on injection bucket after local and global optimization.

Time jitter study (without beam) Timing jitter solely from the timing system should be ≤ 15 ps. Anton provides EVG TTL output channels where the triggers of SR injection kickers come from. This study yields the information of the magnitude of the jitter mainly coming from kicker system.

Time jitters for 4 injection kickers are similar, ~2 ns in RMS and 4 to 5 ns in FWHM depending on where the measurement has been done, less jitter ~4ns right at the pulsar, and more jitter ~5ns after the delay line (Fig. 6). Based on the diagnostic measurements by Douglas Durfee and Peter Zuhoski, the time jitter comes from fiber optics receiver. Each kicker has 10 IGBTs in series triggered by fiber optical receivers.

Jitter of the injection kicker waveform is measured with the rising edge of the waveform as the trigger, and it is ~0.5 ns. The precision of the automated kicker waveform tuning is estimated ~1ns.

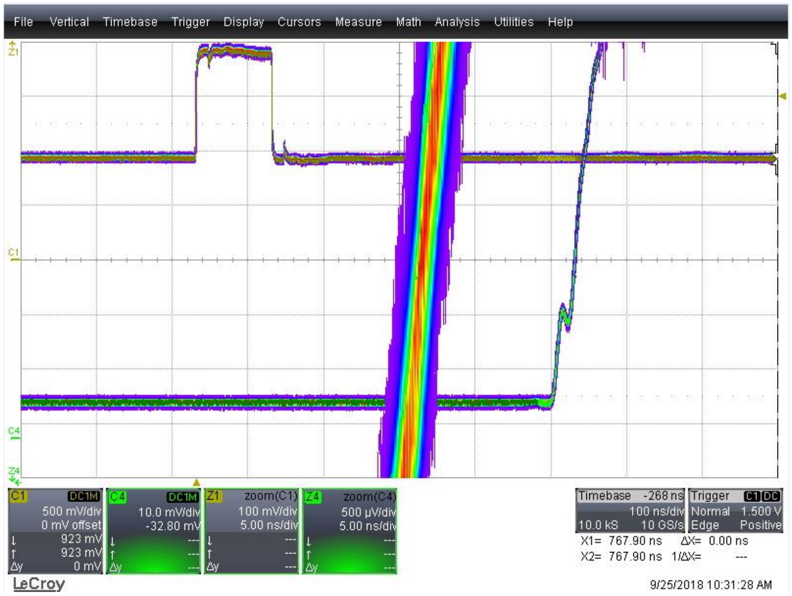

Fig. 6 kicker timing jitter measurement. 2ns in RMS and4.6ns in FWHM.

Plan for future improvement in 2019

First part of this project: the injection transient will be minimized by online optimization of the injection kicker bump matching.

However, based on the timing jitter measurement, the highest priority is to reduce the timing jitter of the injection kickers from 4-5ns down to 1ns level before the upgrade with an adjustable width of the kicker pulse. For the 4-5ns timing jitter of all 4 injection kickers, a 200-500µm injection transient is expected. For this task, Douglas will start from the upgrade of the fiber optical fanout board. If it is successful (jitter <1ns), 40 such boards will be upgraded afterwards. Then we will do the following:

- Injection upgrade with an adjustable width of the kicker pulse: we will begin with hardware modifications of the injection kicker power supplies to achieve an adjustable width of the injection kicker pulse. We aim to reduce the injection oscillation amplitude down to a level which will be nearly transparent to most of the beamline users.
- Simulation studies indicate: for the maximum transient of 50µm at the injection, the ns precision of the kicker waveform adjustment is needed (Fig. 7) and it is within the achievable precision estimated by the power supply group.

Timetable of Activities:

1st – 12th month: Tool development including injection kicker power supply upgrade.

Requirements for modifying SR kicker pulse drives to allow remote tuning of the pulse width:

- Peter Zuhoski provides the document including:

- Add a small Nema 17 Stepper Motor to the Storage Ring Pulse Drivers to allow remote control of the pulse width, etc.
- Tuning range 32 ns of the pulse width should be sufficient.
- Calibrate the variation of the pulse width relative to the inductance change (without beam, plan to do it in the 1st week of September). It will provide the information including the tuning precision of the pulse width.
- Peter's document is attached including hardware, software and labor cost estimations.

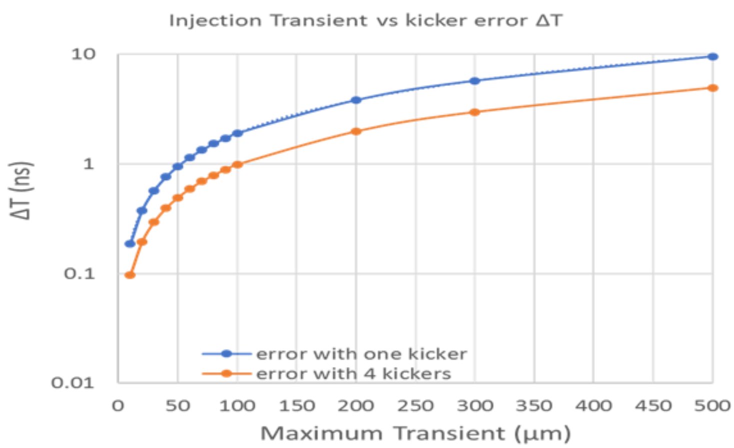

Fig. 7 Maximum injection transient vs kicker error ΔT.

References

[1] X. Huang, J. Safranek, Online optimization of storage ring nonlinear beam dynamics, PRAB 18, 084001 (2015)
[2] G. Wang, *et al.*, "STORAGE RING INJECTION KICKERS ALIGNMENT OPTIMIZATION IN NSLS-II*", IPAC2017, Copenhagen, Denmark.

Appendix: Peter Zuhoski's list:

Modification of the Storage Ring Bump Pulse Driver to permit remote control of the pulse width tuning inductor.

There is a small variation in the pulse width of the half sine wave current pulse produced by the individual Storage Ring Pulse Drivers. To normalize the pulse width between pulse drivers a small tuning inductor was added and is adjusted manually with a screw driver on the back on the Pulse Driver electronic enclosure. It has been proposed to make this tuning possible remotely. To accomplish this, a small stepper motor would be added to the pulse driver to screw in and out the tuning slug used to control the pulse width. Limit switches and an analog position sensor would also be added to give an indication of the slug's location and limit the total travel.

Proposed design would add a small Nema 17 Stepper Motor to the Storage Ring Pulse Drivers to articulate the tuning slug of the Trim Inductor. There is enough room to house the motor, limit switches and position readback in the current enclosure. No additional electronic would be required, just an additional connector and some minor wiring. A cable would be fabricated to connect the motor circuit to the Spellman Power Supply Interface. A new Printed Circuit Card would be designed to provide space for a A4988 stepper motor driver integrated circuit and some I/O bits for the limit switches. The PCB would be a daughter board and mounted on the Spellman interface board. A small cable assembly would be made to route the signals from the daughter card to the spare connector cutout in the rear panel of the Spellman Interface.

Non Recurring Effort

Mechanical Engineering **1 Man Month Engineering**

A) Motor Bracket
B) Shaft Coupler
C) Limit Switch Mount
D) Shaft Position Mount

Electrical Engineering **2 Man Month Engineering**

A) Document changes to Pulse Driver
B) Design stepper Motor Cable Assembly
C) Design stepper Motor Control daughter board for Spellman Power Supply Interface

Software **1 Man Month Engineering**

A) Add Process variables to IOC and Control Page
B) Modification to PSI firmware

Mechanical Part Fabrication **60 Hrs**

A) Brackets
B) Coupler
C) Mounts

Recurring Effort **X6 (4 Units in service + two Units Spare)** **360 Hours**

A) Add Stepper Motor Controller to Pulse Driver
B) Fabricate Cable assembly
C) Assemble Stepper Motor Driver Daughter Board
D) Modify SPSI by adding daughter Board
E) Install and Test

Materials

A) Stepper Motors, Switches, Position Sensor $1K
B) PCB, Electronic components $2K
C) Misc. Wire and Connectors $1K

Metals